radial slit being as near as possible to the point of reappearance, the whole field was crowded with bright lines, fifty or more being visible in the short space between wave-length 5600 and *b*. I noticed no difference in the length of these lines. Clouds and rain soon put an end to all chance of further observations.

Interesting sketches were made during totality of the outer streamers by Captain Masterman and Mr. Osborn, of H.M.S. "Bullfrog," who both used the circular disks arranged so as to cover the brighter portions of the inner corona. The instantaneous view that I obtained of the corona, most exquisitely defined on the white cap of the spectroscope, and the rapid glance I took with an excellent binocular, confirm the positions of the two principal rays drawn by Captain Masterman, but I observed at the same time a shorter ray between the two, which appears otherwise to have escaped detection, and I noticed the leaf-shaped curvature of the ray in the north-west.

The darkness was never much less than that of a fair moonlight night.

II. "Note on the Microscopic Structure of Rock Specimens from three Peaks in the Caucasus." By T. G. Bonney, D.Sc., LL.D., F.R.S., Professor of Geology in University College, London. Received April 5, 1887.

Although our knowledge of the petrology of the Caucasus has been considerably augmented of late years through the labours of Abich, Favre, Tschermak, and others, so much ground still remains untrodden among its mountain peaks that hardly any specimen can be entirely without interest. Those described in the present note have come from the following localities:—(1) The summit of Tau Tetnuld; (2) rocks from the upper part of Guluku; (3) the summit of Elbruz.

The specimens from Tau Tetnuld and Guluku were collected by Mr. W. F. Donkin, during his expedition in company with Mr. Clinton Dent in the summer of 1886, and to the former I am indebted for the following note on the localities.

"Tau Tetnuld is one of the peaks of the central Caucasian chain, in the great Koschtan-Tau group which lies about midway between Elbruz to the N.W., and Kasbek to the E.S.E. From Koschtan-Tau the main ridge forming the watershed runs somewhat north of west, dropping gradually in height; but for some three or four miles forming a magnificent wall on the northern side, covered with a succession of steep snow-slopes and hanging glaciers. A long portion of this ridge, including three more or less well-marked elevations, is called Djanga; the next elevation on the ridge—a much more obvious one, forming indeed a symmetrical snow pyramid—is Tau Tetnuld.

From the north it appears to have a sharp conical summit, but it is really wedge-shaped. Further westwards the ridge falls continuously, a few rocky peaks protruding from it, to a well-marked snow col. The drainage from the whole of this vast wall, from Koschtan-Tau to the col inclusive, collects in a basin, and flows northwards as the Bezingi glacier. The glacier is remarkably level and free from ice-falls, and appears to start almost direct from the foot of the wall, with but little sloping névé. Its course is soon narrowed to a channel of some 1200 yards wide by spurs from the high ridges running northwards on either side. On the west the ridge does not attain any great elevation, but on the east the glacier is bounded by a group of mountains culminating in the great rock-mass of Guluku. This group is completely separated from the Koschtan-Tau chain by the glacier basin above mentioned. Guluku itself is granitic in character, but the lower and surrounding peaks and ridges are schistose and shaly, in parts exactly like the Ober- and Unter-Rothhorn on the north side of the Findelen glacier.* The upper rocks of Guluku are grey in colour and look very like granite from some distance below; then comes a belt of whiter rocks (A), and below that a well-marked red belt (B); both these belts are continuous and nearly horizontal for a long way round the southern side of the peak. Below the red belt the rocks are darker and more mixed (C, D, and E). On the moraine on the east side of the Urban glacier, under Guluku, vast masses of granite had fallen, many of the blocks recently. It is fine grained, and of grey colour (F)."

(1.) *Tau Tetnuld.*—Specimen from the highest rocks about 100 feet below the actual summit, which was covered with snow. Mr. Donkin states that the rock traversed in the ascent appeared to be exactly of the same character. This is a flat fragment of a brownish, rather fissile, but strong, mica schist, about $\frac{1}{3}$ inch thick and nearly 2 inches broad and long. The broad surfaces are spangled with small flakes of a silvery mica, and appear to be those of a "cleavage foliation." Examined microscopically, the chief constitutents are quartz and mica, besides which an iron oxide occurs, frequently in small granules and rods, and more rarely in larger grains. The quartz and mica have a general elongated lenticular arrangement parallel with the broader surfaces of the fragment, and cracks traverse the slide in the same direction. The quartz on applying the polarising apparatus is broken up into a mosaic of different sized grains united by diverse tinted margins, so that we are evidently dealing in each case with one or more grains which have been crushed up and re-cemented. Cavities are sometimes rather numerous, and

* Near Zermatt in the Pennine Alps. These schists are referred to the uppermost group (Graue kalkhaltige Schiefer) in the crystalline series of the Alps.

occasionally tend to range themselves perpendicularly to the lines of cleavage. They are generally minute, sometimes stained internally, both ovoid and irregular in form, usually containing fluid, and with bubbles which, as a rule, are about one fourth the volume of the cavity, but not rarely exceed this. Some of the large grains exhibit the usual indications of being in a state of strain.

The mica is brown, greenish, or colourless. The first and second are biotite, more or less altered. The colourless mica resembles muscovite, but I think that at any rate some of it is a magnesia-potash mica, possibly hydrous, a secondary product after biotite, the iron having separated out. This often remains between the cleavage planes in rods and plates. Possibly some of the smaller flakes of mica may be altogether of secondary origin, but I have no doubt that most of it, including all the larger flakes, is an orginal constituent. These flakes often afford marked evidence of mechanical disturbance. They are bent, twisted, crumpled, and in some cases crushed up. Portions of them, viewed with the polarising apparatus, have a peculiar "powdered" look, which I find very characteristic of a mica that has been to a certain extent crushed *in situ*, so that, while the general outline of a crystal is preserved, there are constant ruptures of continuity and slight displacements of the constituent parts. A few small mineral granules also occur in the slide; some I am disposed to refer to epidote, others to a very impure garnet.

(2.) The specimens from Guluku were collected, partly *in situ* at a height roughly of 14,500 or 15,000 feet above the sea, partly from a moraine, as above-mentioned, on the Urban glacier; hence they represent a considerable mass of the mountain below the level just mentioned. The highest point of Guluku is about 16,500 feet above the sea.

(A.) From the highest rocks reached. A small fragment of rock with indications of a slight cleavage, consisting of a porcelain-white mineral irregularly mottled with one of a pale pistachio-green colour. The former on microscopic examination proves to be a plagioclastic felspar, considerably decomposed, but in parts showing very clearly a lamellar twinning. The extinction angles are generally rather small, probably oligoclase predominates; microlithic flakes of a micaceous mineral, and other decomposition products, are frequent. The other mineral is an epidote, varying from a pale yellow tinge to colourless, and rather impure. It occurs in aggregated and sometimes rather fan-like groups of longish crystals. There are also a few spots of a serpentinous or chloritic mineral. The mechanical disturbance of the rock is obviously posterior to the crystallisation of the felspar, as its crystals are cracked and even sheared, but, at any rate in the main, prior to that of the epidote.

Guluku (B).—A small fragment of a coarse gneissose rock, evi-

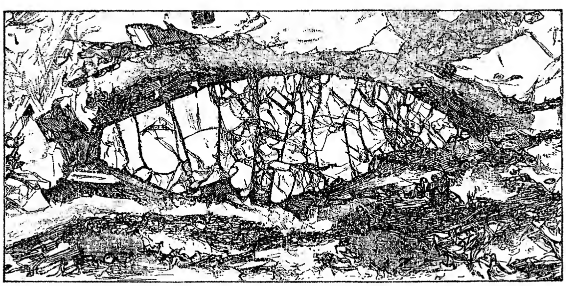
dently containing a considerable amount of a darkish mica, on the weathered surfaces reddish-brown (the "red band"). Under the microscope it is seen to consist chiefly of biotite, felspar, considerably decomposed, in part at least plagioclase, and quartz. The biotite is in places altered into a greenish chloritic mineral, in others is "bleached" by parting with its iron. A white mica, however, which occurs in good sized flakes, appears to be an occasional original constituent. The rock has evidently been much crushed. The quartz is cracked and displaced, the felspar has been broken up, and parts of the original crystals are now occupied by a sort of irregular mosaic or mixture of felspar, quartz, kaolin, and white mica. The felspar crystals are occasionally interrupted by roundish inclusions of quartz, such as one often sees in the oldest gneisses. These may be of secondary origin, but I find nothing to prove it. The original quartz grains, where adjacent to the crushed felspar, appear to have been augmented by secondary deposits of quartz in optical continuity. The mica in parts of the slide shows marked indications of mechanical disturbance, and a reddish garnet at the edge has been distinctly crushed out, as is more fully described in (C).

Guluku (C).—This specimen, in shape roughly a right-rhomboidal prism about $1'' \times 1'' \times \frac{1}{2}''$, has for its larger faces parallel joint surfaces; two others are "sheen surfaces," parallel with which the fractured faces exhibit a foliated structure. The rock appears to be a strong rather compact mica-schist, dark in colour, with a few very thin lighter-tinted bands.

The principal minerals are quartz, mica, garnet, iron oxide, and a quantity of a brownish mineral, sometimes very fibrous. The quartz occurs mostly in granules of moderate size, occasionally including a little minute rutile (?) and mica. It is on the whole fairly clear, but here and there cavities are pretty numerous. These frequently contain bubbles, which, though very variable in relative size, are generally smaller than in the Tau Tetnuld rock, perhaps commonly about one-sixth or one-seventh of the whole volume. The mica constituent is chiefly biotite or its alteration products, often a greenish chloritic mineral, sometimes a whitish hydrous mica, both with interlamination of iron oxide. The garnet is colourless in thin slices, and occasionally exhibits, along cracks, alteration for a short distance into a chloritic mineral. Some of the larger granules of iron oxide are hematite. The pale-coloured rather filmy or fibrous mineral is certainly in some cases a secondary product after a felspar, the usual aggregate of a minute micaceous or kaolinitic mineral. Other parts, however, consisting of narrow undulating bands of an aggregated fibrous mineral, like a small lock of wavy hair, I was at first disposed to regard as fibrolite, but after repeated examination I am unable to decide. They resemble in some respects a fibrous mica, but their extinction

does not appear to agree with this mineral (though accurate measurements are difficult to obtain) for it seems markedly oblique.

It is evident at a glance that this rock has been subjected to a great pressure normal to the conspicuous foliation. The garnets have been cracked and crushed out, so as to have become elongated ovals in shape. A glance at the diagram will render a more minute description needless, and will show that the garnet was more or less flattened out before it broke. The quartz grains also are cracked, being sometimes only a little, sometimes much displaced. This mineral, however, does not appear to have been so completely crushed up as in the Tau Tetnuld schist. Occasionally a small grain, adjacent to the (original) felspathic constituent, has escaped altogether. The felspar has, I believe, often been crushed out, and then converted into the abovenamed microlithic mineral. The larger mica flakes are twisted about in the manner usual in a rock which has been crushed. Study of this slide seems to me to show conclusively that this rock, anterior to the crushing, was a moderately coarse crystalline rock, consisting chiefly of quartz, felspar, biotite, and garnet, probably a rather micaceous gneiss.



Garnet, squeezed out and cracked ; surrounded by biotite, quartz and the fibrolitic mineral. × 25 diam.

Guluku (D).—A small fragment of a micaceous granitoid rock.

Except for the greater abundance of biotite and the smaller amount of quartz this rock is closely allied to the next described ; the felspar is a little more decomposed, and small garnets are rather more numerous. With these modifications the description given below applies here, and this rock, too, has evidently undergone about a similar amount of mechanical disturbance. Another small fragment from about the same level contains more white mica, but as the general aspect suggests no important difference, and it is not a very promising specimen, I have not had a section made. This occurs at a slightly lower level than (B), and the two are about 100 feet below (A).

Guluku (F).—Section from one of two specimens representing numerous large blocks of granite fallen from west side of Guluku.

This is a fairly coarse-grained rock, chiefly consisting of a white felspar and dark mica, not rich in quartz. The mica is mainly biotite in good preservation. There is also a certain amount of a white mica which appears to be an original constituent and to belong to the muscovite group. The felspar is occasionally replaced by kaolinite and micaceous minerals, but much of it is in good preservation; sometimes one part of a crystal is reduced to an "earthy" condition, while the rest is quite fresh. Most of the crystals show the twinning of plagioclase, generally on the albite type, but occasionally on the pericline. One of the grains appears to be microcline. I have measured the extinction angles of several parallel lamellæ; it is difficult to get very satisfactory results, but, as in two of the best cases, they appear distinctly too large for albite, between 30° and 40°, the felspar is probably oligoclase. There are two or three small colourless garnets, with probably a little apatite. The quartz contains cavities, in which small bubbles are usually present, about one-sixth or one-seventh of the volume.

This rock has evidently been subjected to a certain amount of mechanical disturbance since its consolidation. The quartz grains are cracked and show strain-polarisation. The felspar lamellæ are occasionally bent, now and then cracked across, but the effects are slight compared with the other cases.

Mr. Donkin also collected a specimen some miles further down the valley which resembled the rock in a neighbouring cliff. This appears to be a reddish rather fine-grained felspathic granite, but as it was not obtained *in situ* I have not had a slice prepared.

The evidence of these specimens does not appear sufficient to warrant any positive statement as to the origin of these Caucasian rocks. The structure of one (D) seems rather to favour the idea of its having been a true granite (*i.e.*, an igneous rock); the same is true also of (F); while in another (B) there is a structure, which I have some reason to think characteristic of the Archæan gneisses.* But in the present state of our knowledge it would be unsafe to rely too much upon the latter criterion, because we do not yet know what modifications may be introduced by subsequent rearrangement of mineral constituents. It has indeed been proved in the case of hornblendic rocks, that the original structures, characteristic of crystallisation from a state of fusion, may be wholly obliterated;

* The same difficulty exists in the case of some of the more highly crystalline rocks of the Alps. Favre ('Recherches—Chaîne du Caucase,' p. 70) states that the central part of the Caucasus is "granite," which he compares with the protogine of the Alps, with a considerable belt of crystalline schists on the north, and an intermittent one of the same, followed by slates, on the south.

the same may take place also with granitic rocks. Still, even if this mode of metamorphism has occurred, there is some reason to believe that it dates usually, if not invariably, from a very remote period. We can, however, in my opinion, venture to assert that these Caucasian rocks, after they had assumed a crystalline condition, underwent great pressures, regional rather than local in their operation, which to some extent crushed the constituents, and gave rise to certain mineral changes. It seems then a legitimate inference that in this part of the Caucasus, as in the Alps, the fundamental rocks consisted of crystalline rocks of more than one type, at a period long anterior to the operation of the pressures which folded this part of the earth's crust and upreared the mountain range.

(3.) The huge mass of Elbruz appears to consist mainly of volcanic rock, and is crowned by two crater-peaks almost equal in height. Of these the eastern, which is believed to be very slightly the lower of the two, was ascended for the first time on July 31st, 1868, by Messrs. Freshfield and Moore. On this occasion the western summit was so entirely concealed by clouds that its existence was not even suspected. The western summit was first ascended on July 29th, 1874, by Messrs. Grove and Walker. Its "crater considerably exceeds in size that on the twin summit, and is probably about $\frac{3}{4}$ of a mile in diameter. The wall is perfect for some two-thirds of its former circuit, but on the south-west side a vast piece has fallen away, and a great glacier now flows down from the gap." The little peak forming its highest point, juts up on the north-eastern segment of the limb. Its height above the sea, according to the Russian survey, is 18,526 feet, the eastern summit being 95 feet lower. The col between the two summits, according to Mr. Grove, is about 17,350 feet. The specimen collected by Mr. Walker was from the highest rocks traversed on the western peak, perhaps about half-way between the col and the summit. It is a rough slab of a grey lava, with occasional small irregularly-shaped vesicles, and scattered crystals of a whitish felspar up to about $\frac{1}{4}$ inch in length. The weathered parts are of a lightish-brown colour.

Microscopic examination shows that the rock has a clear glassy base crowded with minute lath-like felspar microliths, apparently oligoclase, and occasional specks of opacite and aggregates of ferrite: possibly some minute granules of a pyroxenic mineral are present. To the same epoch of consolidation may belong some occasional elongated crystals of a light-coloured hornblende, but this is uncertain —there are a few grains of iron oxide, probably hematite. The larger crystals in the slide certainly belong to an anterior consolidation—these are (1) a dark brown hornblende, often with rounded outline, and sometimes blackened with included opacite; (2) a felspar, which generally resembles labradorite or andesine, but in one or two cases

may possibly be sanidine. It is often rounded or broken in outline, is always greatly cracked, and contains many inclusions of a pale brown glass. One grain, indeed, consists very largely of glass, in which the crystalline parts are, so to say, embedded. This suggests that the mineral has been melted down *in situ* along the lines of natural fracture, rather than that it has incorporated the glass in crystallising. There are occasional cavities in the felspar, with bubbles varying in their relative size, which do not move. Grains of quartz, as observed by Tschermak ('Mineral. Mittheil.,' 1872, p. 108) in specimens brought by Favre from the lava streams lower down the mountain, do not occur in this specimen. A fluidal structure is barely indicated. The rock may be named a hornblende-andesite. I have compared the slide with one from the upper part of Ararat (lent me by Professor Judd), and with my own collection of andesites and allied rocks from Auvergne, Germany, Hungary, Italy, Old Providence Island, and the Andes, but it differs varietally from all.

III. "On the Distribution of Strain in the Earth's Crust resulting from Secular Cooling, with special Reference to the Growth of Continents and the Formation of Mountain-chains." By CHARLES DAVISON, M.A., Mathematical Master at King Edward's High School, Birmingham. Communicated by Prof. T. G. BONNEY, D.Sc., F.R.S. Received April 7, 1887.

(Abstract.)

The paper is founded on—

1. Sir W. Thomson's and Professor G. H. Darwin's researches on the rigidity of the earth.

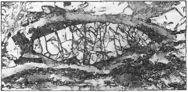
2. Sir W. Thomson's investigation on the secular cooling of the earth.

3. The contraction theory of mountain formation.

I. *The Distribution of Strain in the Earth's Crust resulting from Secular Cooling.*

The following problem is solved:—A globe, of radius r, is surrounded by a number of concentric spherical shells, called A_1, A_2, A_3 . . . ., of thickness a_1, a_2, a_3 . . . . respectively. The globe remaining at its initial temperature, the shell A_1 is cooled by $t_1°$, the shell A_2 by $t_2°$, in the same time, and so on. The linear coefficient of expansion being e, and the same for all the shells, it is required to find the distribution of strain resulting from this method of cooling.

An expression is found giving the change of radius of the inner surface of any shell. Supposing all the shells to be of equal thick-



Garnet, squeezed out and cracked; surrounded by biotite, quartz and the fibrolitic mineral. × 25 diam.